SILICON TRANSISTOR UHF TUNER

By Thomas B. Mills

I INTRODUCTION

With the introduction of the SE3002 uhf entertainment transistor, transistorized uhf tuners can now be built with superior performance and at no more cost than vacuum tube units. Operational stability, negligible drift, and freedom from microphonics are prime advantages. Low power consumption and small size allows compactness of construction without heat dissipation problems. The non-degradation of performance with time of the transistor assures long life with minimum maintenance. The transistor tuner eliminates the tube socket, heater choke and associated bypass capacitor and wiring. Since no heater power is required, only one power lead is needed which can be the center conductor of the i-f cable.

The uhf tuner described in this note was built to demonstrate the performance possible with the SE-3002 and to provide guide lines for designers. This tuner is shown in Fig. 1. The transistor is packaged in epoxy plastic which gives lower stray capacitance since the can is eliminated; also its solid form gives mechanical strength to the entire assembly.

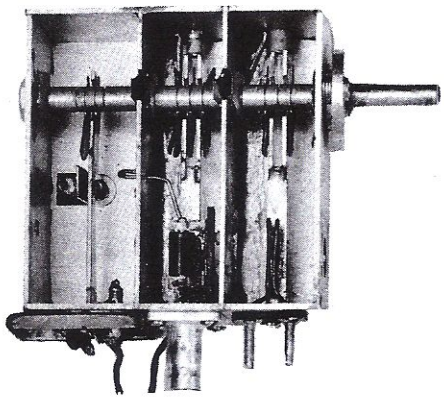

FIG. 1. External view of uhf tuner.

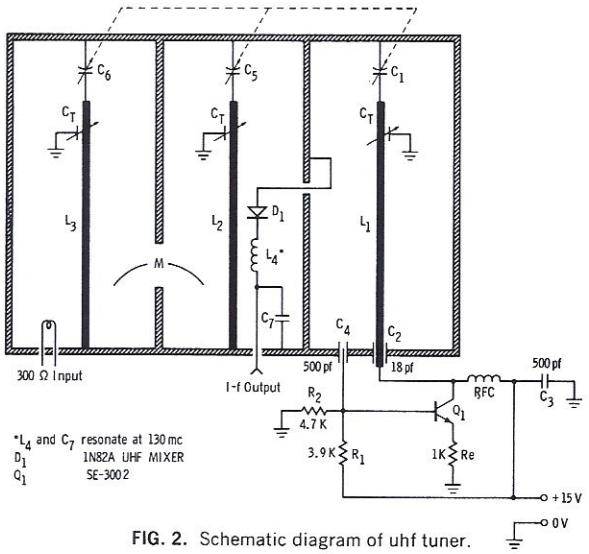

FIG. 2. Schematic diagram of uhf tuner.

The schematic diagram of the tuner is shown in Fig. 2. It includes passive r-f preselector circuits, a uhf local oscillator and a diode mixer. Performance specifications are given in Table I.

TABLE I
PERFORMANCE SPECIFICATIONS

TUNING RANGE	465 mc to 890 mc
INTERMEDIATE FREQUENCY	45 mc with oscillator above carrier
LOCAL OSCILLATOR STABILITY	Better than ± 150 kc shift ± 10% supply voltage variation Better than -200 kc shift for +40°C transistor case temp. rise
OVERALL LOSS	Less than 11 db over the frequency range of operation
BANDWIDTH	Approximately 10 mc over the frequency range of operation
NOISE FIGURE	Less than 15 db over the frequency range of operation
IMAGE REJECTION	Greater than 50 db over the frequency range of operation
POWER CONSUMPTION	Less than 150 milliwatts

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II TUNER DESCRIPTION

Oscillator Circuit

The primary design goal in building the oscillator was to obtain good frequency stability both with temperature and supply voltage variations, and to keep cost of materials low. Power output and efficiency was considered to be of secondary importance, since the total power required by the circuit is very small, less than 150 milliwatts.

A grounded-base oscillator is used with a tank circuit in the collector. Feedback from the collector to emitter through the transistor's internal capacitance is usually sufficient to cause oscillations. If additional feedback is needed, it can be provided by a "gimmick" capacitor.

Biasing of the oscillator is not critical as long as certain ΔV_{CB} and ΔI_C ratios are maintained, which are discussed in the Appendix. A V_{CB} of 8 volts and I_C of 7 mA were chosen in this circuit, giving a dissipation of 56 milliwatts which is well within the transistor's rating.

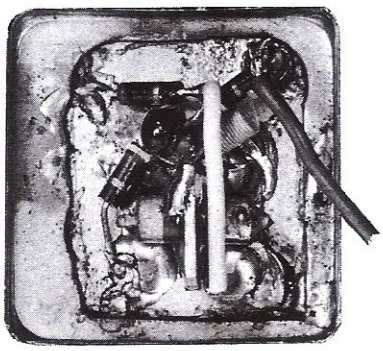


FIG. 3 View of oscillator.

The tuned-line of the oscillator tank can be seen in Fig. 1. The transistor end of the line is terminated with a fairly large capacitor to ground which provides a low impedance for the transistor. This minimizes the effect of parameter change on oscillator frequency. It was found that the capacitor must be of very low inductance to insure proper operation.

Mixer Circuit

The mixer circuit consists of a 1N82A uhf mixer diode coupled to a tuned r-f line and the local oscillator by means of a wire loop. The diode rectifies the local oscillator driving voltage producing a d-c operating bias; and mixing action is obtained from the nonlinear volt-ampere characteristics of the diode. The output of the mixer circuit is terminated in a low-pass filter L_4 and C_7 and the input of the i-f amplifier. The low-pass filter is self resonant at approximately 150 mc, thereby passing the i-f output of the tuner, but attenuating the local oscillator and incoming uhf signals.

Diode current can be adjusted by varying the area and location of the wire loop inside the oscillator compartment. The shape of the diode current vs frequency curve is governed largely by the placement of the loop since the voltage standing wave on the oscillator tank line determines the voltage induced in the loop. Since the output of the transistor decreases with increasing frequency, it is desirable that coupling be adjusted to increase with frequency so that the drive to the mixer is nearly constant.

RF Tuned Circuits

The tuned circuits consist of capacitively tuned lines which are self resonant at approximately 1000 mc. The capacitors C_1, C_5 and C_6 are approximately 4 pf. At the higher end of the uhf television band, the lines appear as capacitively terminated transmission lines, while at the lower end of the band they are described more accurately as lumped inductors tuned with lumped capacitors. The unloaded Q of the mixer and r-f tanks measured approximately 500 from 500 mc to 900 mc. The loaded Q of these circuits is a function of bandwidth and frequency, which is shown in Fig. 5. Coupling between the r-f and mixer tanks is accomplished by means of a 3/4" x 1/2" window in the partition between these compartments.

Mechanical Description

The chassis was made of 1/16" steel and the tank lines of 3/64" steel; the heavy gauge provides

mechanical strength and the use of steel minimizes changes of dimensions with temperature. The steel was silver plated to provide high conductivity at uhf frequencies, effectively raising the Q of the tuned circuits.

Referring to Fig. 3, it can be seen that all oscillator circuitry except the tank line was mounted externally to the chassis and shielded with a small metal cover. It is especially important to keep the base and collector leads of the transistor as short as possible, (less than 1/8").

III PERFORMANCE

The stability of the oscillator is better than ± 125 kc for ± 10% change in supply voltage, and oscillator frequency shift with temperature change is less than -200 kc for + 40°C transistor case temperature rise. Both of these factors, shown in Fig. 4, are related since the same transistor parameters, especially output impedance, change with both temperature and supply voltage. We have found with various oscillator circuits that if good stability with supply voltage variation has been achieved, good temperature stability will result.

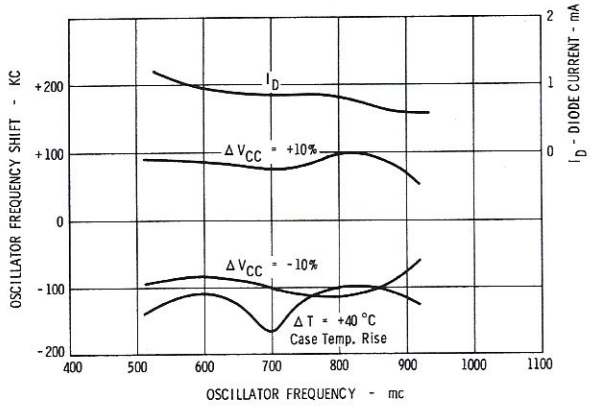
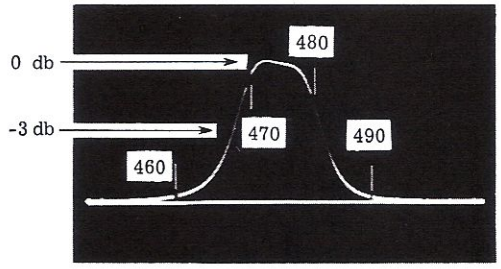


FIG. 4. Oscillator stability and diode current.

The mixer diode bias current was chosen to have a nominal value of 0.8 mA since this is within the operating region of low noise figure and minimum conversion loss. The bias current vs local oscillator frequency is shown in Fig. 4.

The tuner's bandpass characteristics were adjusted with the aid of a sweep generator, using a 50Ω to 300Ω uhf balun between the generator and the tuner input, the tuner's i-f output being terminated in a 50Ω detector. By proper adjustment of the mixer, r-f and antenna coupling, a 10 to 20 mc bandwidth response curve was obtained over the uhf band, and is shown in Fig. 5. The overall loss was measured and found to be between 7db and 10db over the tuning range.



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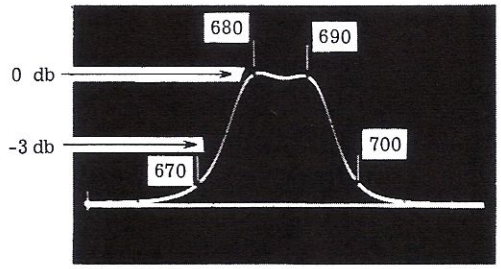

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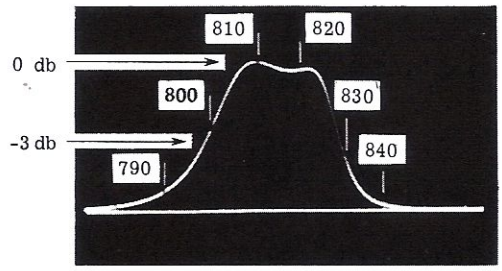


FREQUENCY IN MEGACYCLES

FIG. 5. Tuner response curves.

The noise figure was found to be between 9.6 db and 15 db over the tuning range. It is felt that an improvement could be obtained by further optimization of the mixer diode coupling.

Image rejection was found to be between 54 db and 60 db over the tuning range.

IV CONCLUSION

The design of an efficient uhf tuner must consider the special properties and low impedances of the transistor. Although the general design techniques are the same as for a vacuum tube the procedures described in this paper should be used for optimum performance. Transistorized uhf tuner design is not exceedingly critical, however, as several versions of breadboarded circuits were built and all operated without difficulty.

It was found that the circuit has a wide tolerance to transistor parameter variations. A number of transistors selected at random were tried and the tuner's performance was essentially the same for each.

V APPENDIX

Oscillator Design Considerations

The oscillator design that follows was given by P. Alderisio in Fairchild APP-48, "UHF Oscillator for Television Tuners".

The parameter of major importance in the oscillator design is h_{ob}, the common-base output admittance with the input open circuited. In order for oscillations to occur, the real part of h_{ob} must be negative, and must be larger than the transformed load and tank loss admittance presented to the transistor.

The r-f equivalent circuit of the oscillator is shown in Fig. 1A. The common-base output admittance of the transistor presented to the tuned circuit has been shown as

$$h_{ob} = Y_{22b} - \frac{Y_{12b}\,Y_{21b}}{Y_{11b}} \qquad (1A)$$

in terms of the common-base short circuit Y parameters.

The 1 kΩ bias resistor across the transistor input is sufficiently large to prevent a large error in the calculation of h_{ob}.

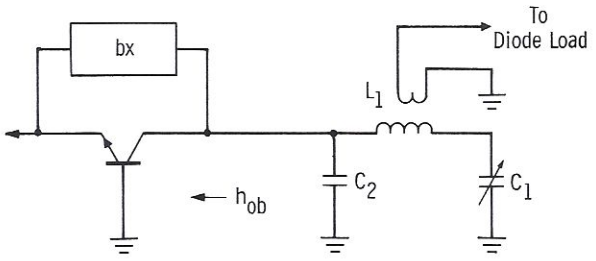


FIG. 1A. R-f equivalent circuit.

A typical value for h_{ob} is -4.4 + j14.1 mmhos at 930 mc which shows a negative real part necessary for oscillation. Looking at equation (1A), it is evident that h_{ob} is negative due to the second term, since Y_{22b} is positive for all real frequencies. In order to maximize the output power of the oscillator, the second term of (1A) may be modified with the addition of a feedback admittance jb_x (see Fig. 1A). This changes the second term of (1A) to:

$$\frac{(g_{12b} + jb_{12b} + jb_x)\;\;(g_{21b} + jb_{21b} + jb_x)}{Y_{11b} + jb_x}$$

Maximizing the real part of the numerator gives

$$b_x = -\frac{b_{12b} + b_{21b}}{2} .$$

This turns out in practice to be a fairly small capacitor of about 0.5 to 5 pf.

To obtain greater oscillator stability, the reactive part of h_{ob} must be swamped out. In effect, the transistor's output impedance consists of a small capacitor C_{ob}, typically 1 pf. C_2 is used for this purpose and hence should be as large as possible (about 15 pf has been found to be satisfactory). This capacitor should present a very low amount of inductance between the line and ground; hence, the physical shape becomes quite important. In the oscillator described here, a small feed-through ceramic bypass type was finally used, although a plated barium titanate disk soldered directly between the line and ground also worked quite well.

Oscillator stability can be further improved by optimizing the d-c biasing. Since the output capacitance of the transistor decreases with increasing

collector-to-base voltage and increases with increasing collector current, these two effects can be made to minimize output capacity change with supply voltage variations.

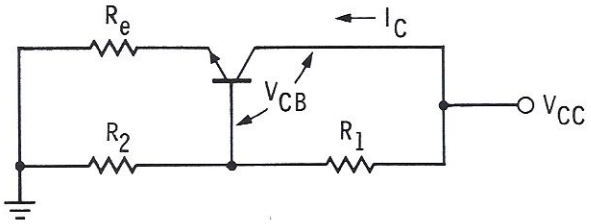


FIG. 2A. D-c biasing circuit.

The biasing scheme is shown in Fig. 2A. Here

$$V_{CB} = \frac{V_{cc} R_1}{R_1 + R_2} \quad , \quad \Delta V_{CB} = \frac{\Delta V_{cc} R_1}{R_1 + R_2}$$

and

$$\Delta I_C = \frac{\Delta V_{cc} R_2}{R_e (R_1 + R_2)}$$

solving for

$$\frac{\Delta V_{CB}}{\Delta I_C}$$

$$\frac{\Delta V_{CB}}{\Delta I_C} = \frac{R_1}{R_2} R_e$$

Measured data on the prototype oscillator showed that if $\Delta V_{CB} = +3$ V and $\Delta I_C = +4$ mA, the output frequency remained constant.

Therefore:

$$\left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{\Delta f = 0} = 750\,\Omega = \frac{R_1}{R_2} R_e$$

Choosing

$$R_e = 1\,\text{K}, \quad \frac{R_1}{R_2} = 0.75$$

with

$$R_2 = 4.7\ \text{K}, \quad R_1 = 3.5\ \text{K}.$$

In practice, $R_1 = 3.9$ K was used with satisfactory results.

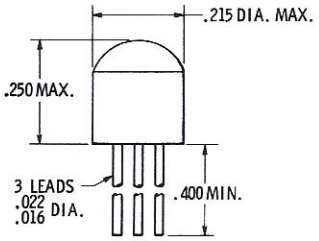
ACKNOWLEDGEMENT

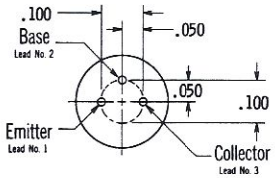
A Sickles uhf tuner was used as the foundation for the tuner described in this paper. The use of a commercial unit expedited the design of the silicon planar transistor circuitry without the problems attendant with physical construction and tuning mechanisms.

SE-3002
UHF OSCILLATOR AND AMPLIFIER

GENERAL DESCRIPTION - The SE-3002 is an NPN double-diffused silicon planar transistor designed for uhf oscillators and high frequency amplifiers in entertainment applications. It features a solid plastic package which resists shock and vibration and completely seals out possible contaminants.

PHYSICAL DIMENSIONS
EPOXY PACKAGE





NOTE : All dimensions in inches

ABSOLUTE MAXIMUM RATING (25°C)

V_{CBO} - Collector to Base Voltage	30 Volts
V_{CEO} - Collector to Emitter Voltage	12 Volts
Total dissipation at 25°C Case Temperature	0.5 Watt
at 65°C Case Temperature	0.3 Watt
at 25°C Ambient Temperature	0.2 Watt

ELECTRICAL CHARACTERISTICS (25°C unless otherwise noted)

Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Conditions
C_{ob}	Output Capacitance			1.7	pf	V_{CB} = 10 V I_E = 0
f_T	Gain Bandwidth (f = 100 mc)	600			mc	I_C = 8 mA V_{CE} = 10 V
P_o	Power Output at 930 Mc		8		mW	I_C = 10 mA V_{CB} = 10 V
I_{CBO}	Collector Cutoff Current			0.5	μA	V_{CB} = 15 V I_E = 0
BV_{CBO}	Collector-Base Breakdown Voltage	30			Volts	I_C = 0.1 mA I_E = 0
V_{CEO}(sust)	Collector-Emitter Sustaining Voltage	12			Volts	I_C = 3.0 mA I_B = 0